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X-RAY FLUORESCENCE ANALYSIS OF PEWTER: ENGLISH AND SCOTTISH MEASURES

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INTRODUCTION

Energy dispersive x-ray fluorescence spectroscopy has become an increasingly useful tool for the analysis of museum objects. Its application to the analysis of ancient coins, ceramics, jewelry and other materials is well documented (Brown 1973, Hall 1973, Metcalf 1973). The Analytical Laboratory of the Henry Francis du Pont Winterthur Museum has, since 1970, used this versatile technique for the analysis of the silver, brass and pewter objects in the Museum's extensive collection of early American decorative arts (Hanson 1973, Carlson 1976). As part of this program, a large collection of about 1500 pieces of British and American pewter objects has been analyzed. Some of the data obtained has appeared as an appendix in a recent book (Montgomery 1973), while the bulk of the pewter analyses have been summarized in a forthcoming article (Carlson 1977). This paper is concerned with the x-ray fluorescence analysis of some 80 British pewter wine measures which have not been discussed previously.

EXPERIMENTAL

A combination of electronic components made by the Kevex Corporation, Packard Instrument Company and the Hewlett-Packard Company, and described in a recent article by V. F. Hanson (1973), was used for the analysis of all the pewter objects. Briefly, the instrumentation consists of an x-ray emitting radioactive source ($^{109}_{48}Cd$) above which the pewter object under analysis is placed. The x-rays excite the electrons in the alloy which in turn emit x-rays characteristic of the elements making up the alloy. This fluorescent radiation is detected by a solid state lithium-drifted silicon detector, sorted according to energy, and stored in a 512-channel memory bank. The contents of the memory banks are continuously displayed on an oscilloscope. Once a run is complete, the data are transferred from the memory bank to a Hewlett-Packard 2114B computer which is programmed to subtract a previously stored baseline of tin, sum the peaks of interest over five contiguous channels, and then calculate the weight percent of each of 13 elements using factors derived from the analysis of a standard pellet of known composition (84% tin, 5% lead, 5% antimony, 2% each copper, zinc and bismuth). Teletype printouts of all standard runs and analyses are recorded, and permanent records of the oscilloscope display are recorded on a Hewlett-Packard 4004B X-Y plotter. A typical chart with peaks appropriately labeled is shown (figure 1). Peak 1 is produced by Compton backscatter from the x-ray source. Peak 2 results from silver radiation from the decaying cadmium source.

In the analysis of pewter, a Schwenker-Ulig 'spot-finder' automatically turns off the accumulation phase of analysis when the tin peak reaches a pre-determined level. Two

p 147–155 + 5 pages photographs between p 148 and p 149

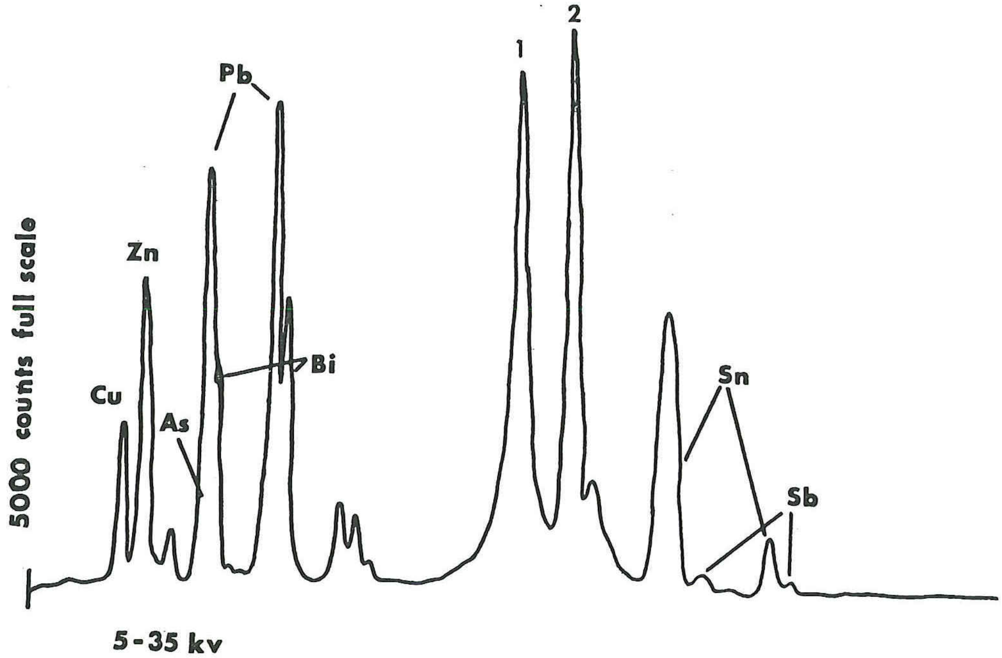


Figure 1 *Typical spectrum from* x-*ray fluorescence analysis of pewter*

thousand counts on the tin peak are chosen to provide a minimal run time (about 1.5 min) without sacrificing precision and accuracy. Since the computer can accomodate a maximum of about 32 000 counts per channel, objects with very high lead content (Pb > 35%) cause the channels containing lead peaks to recycle, producing meaningless results. In order to keep the lead level below 32 000 counts, the number of counts for tin is limited to 500 for pieces with high lead content.

Pewter is an alloy consisting primarily of tin and lead with smaller amounts of copper, antimony, zinc and bismuth, and occasional trace amounts of arsenic, iron, silver and others. Although data have been accumulated for 13 elements in each pewter object, we have limited this study to an analysis of the data on the four major components—tin, lead, antimony and copper.

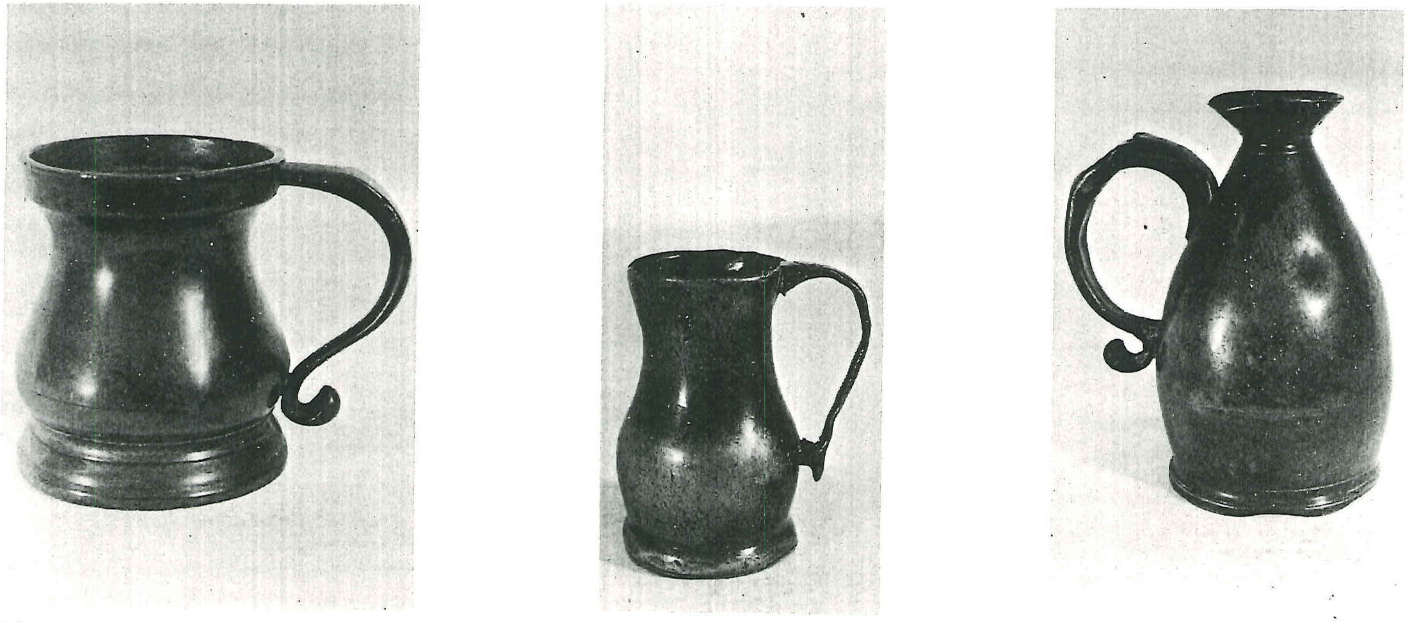
The quality of any given pewter piece is determined by subjective evaluation using such criteria as style, workmanship, condition, etc. But such standards are not useful in a scientific evaluation of quality. Therefore, we have chosen to use the tin content of a pewter piece as an indication of its quality, since pewter collectors have generally recognized the axiom 'the more tin, the better' (Englefield 1951).

The precision and accuracy of the x-ray fluorescence analysis of pewter has been discussed at length in a forthcoming publication (Carlson 1977). The data from 10 replicate analyses of our pewter reference standard and of a pewter plate made by William Will (1764–98) of Philadelphia from the Winterthur collection are summarized in table 1. The precision or reproducibility of three of the four components of interest, tin, lead and copper, is excellent. The precision for antimony, especially at lower concentration levels, is somewhat poorer. In

facing page 148

(*a*) (*b*) (*c*)

Plate 1 *English baluster measures showing various types of thumbpieces.* (a) *Hammerhead. Gallon.* $\mathrm{I}_{\mathrm{W}}\mathrm{F}$ *and unidentified touch on lid. Height to lip:* $11\frac{1}{8}$*". Seventeenth century (Currier Gallery of Art, Manchester, N.H.).* (b) *Bud. Pint.* $\mathrm{W}^{\mathrm{M}}{}_{\mathrm{M}}$ *on lid. I:L touch of John Langford, London* 1719–57 *(private collection).* (c) *Double volute. Quart. Touch of Robert Bush, Sr, of Bristol and Bitton. Height to lip:* $6\frac{3}{4}$*".* c. 1755 *(private collection).*



(*a*) (*b*) (*c*)

Plate 2 *Other English measures*. (a) *Bulbous. One-fifth of a quart. Lidless. Height* $3\frac{1}{4}''$. *Worn oval touch* (DIALS) *inside bottom*, c. 1700–1830 (*private collection*). (b) *Jersey. Capacity 65 cc. Lidless. Height* $2\frac{3}{4}''$. *Marked with crowned* GR *on lip to right of handle*. c. 1780–90 (*private collection*). (c) *West Country. Pint. Unlidded. Height 6''. M. Fothergill & Sons, Bristol*, c. 1830 (*private collection*).

(*a*) (*b*) (*c*)

Plate 3 *Scottish measures.* (a) *Baluster. Imperial pint. Height* $5\frac{1}{8}''$. *Mark of David Gourlay, Edinburgh,* c. 1826–30 (*private collection*). (b) *Tappit-hen. Scots pint. Height* $9\frac{5}{8}''$. IW *on lid. Bears dated* (1749) *touch of William Hunter of Edinburgh on rim* (*private collection*). (c) *Pot-bellied. Scots pint. Unlidded. Height* $8\frac{5}{8}''$. IW *on handle*, c. 1700–40 (*private collection*).

Plate 4 *Baluster measure. Quart. Height* $6\frac{3}{4}''$. *Line touch W. Scott on handle*, c. 1794–1826 (*Currier Gallery of Art, Manchester, N.H.*).

Plate 5 *Baluster measure. Triple domed. Quart. Height overall 9″. Attributed to W. Scott, Edinburgh*, c. 1794 (*private collection*).

Table 1 *Precision of X-ray fluorescence analysis of six major components of pewter*

	Weight (%)					
	Tin	*Copper*	*Lead*	*Antimony*	*Bismuth*	*Zinc*
Pewter reference std. (10 replicate analyses)	84.93±0.12	2.04±0.04	5.0±0.05	4.82±0.18	1.98±0.03	2.01±0.02
William Will plate (observe) (10 replicate analyses)	90.57±0.63	0.39±0.03	7.61±0.50	1.06±0.22	0.26±0.02	0.02±0.01
William Will plate (reverse)	91.30±0.43	0.43±0.03	6.80±0.46	1.16±0.19	0.24±0.02	0.01±0.01

the pewter analysis, antimony and tin are excited by a secondary peak (88 kv) of the ^{109}Cd source. Both the low intensity of this line and its high energy compared to the binding energies of the tin and antimony $K_{\beta 1}$ peaks contribute to the low excitation efficiencies for tin and antimony. Fewer counts are thus obtained for these elements during the analysis time, resulting in a reduction in precision. Since tin is, in most cases, the major element, it suffers less from the lower efficiency of excitation than does antimony. Both the accuracy and precision of tin would suffer in the case of objects with very high lead contents (i.e. markedly reduced in tin), because of the relatively fewer tin counts produced.

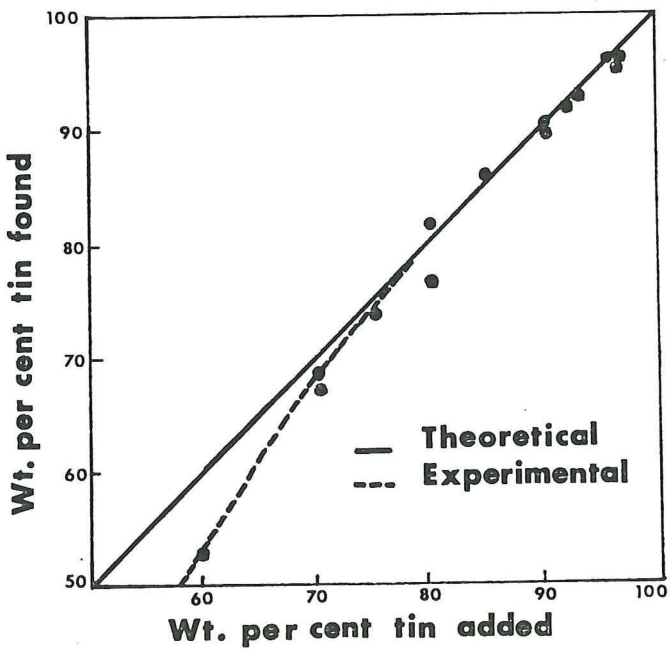


Figure 2 *Accuracy of X-ray fluorescence analysis of pewter*

The accuracy of the x-ray fluorescence analysis method for pewter was determined by analyzing several 'known' pewter billets and pellets prepared and analyzed by wet chemical methods. If the 'found' tin content is plotted *vs.* the tin 'added' to the samples, a curve is obtained which deviates from the theoretically expected straight line as the amount of tin decreases (figure 2). At the 80% tin level, a 1% error exists, while at 55% tin, the error is about 10%. To obtain an estimate of the absolute tin content for those pieces whose analyses show less than 80% tin, an empirical correction can be made; however, such corrections have not been applied to the data presented in this paper. Comparisons of the relative composition of one piece to another have been made without correction, since all samples are run using identical conditions and using the same reference standard.

RESULTS AND DISCUSSION

English measures

Tavern wine measures made of pewter date from at least the sixteenth century in the British Isles. Their size over the years varied according to different capacity standards and ranged from the very small quarter gill (1/16 pint) to the gallon.

The compositional data for all English measures analyzed are summarized in table 2. Previous analyses of more than 200 other pieces of English pewter (Carlson 1977) have

Table 2 *X-ray fluorescence analysis of English measures*

				Weight (%)			
Type	*Period*	*No.*	*Part*	*Tin*	*Copper*	*Lead*	*Antimony*
Lidded baluster	*c.* 1680–1800	15	Base	69.0±6.7	1.7±1.4	25.6±5.6	0.59±0.54
		17	Side	69.7±5.5	1.3±0.8	26.0±4.8	0.76±0.65
		17	Handle	68.6±7.3	1.3±0.6	27.6±6.7	0.61±0.58
		15	Lid	70.7±6.7	1.2±0.6	25.2±6.1	0.91±0.95
Pear-shaped tavern (lidless)	*c.* 1790–1900	11	Side	82.8±11.7	1.0±0.5	12.7±10.7	2.2±1.0
		11	Handle	84.5±8.0	0.8±0.4	12.6±15.8	0.56±0.99
		6	Base	83.3±13.1	1.0±0.3	12.3±12.0	2.0±1.3
Lidded Jersey	*c.* 1730	3	Base	72.0±9.9	1.2±0.3	23.3±9.9	0.75±0.53
		3	Side	65.3±18.5	1.0±0.2	29.4±16.3	0.69±0.62
		3	Handle	64.4±17.1	1.2±0.2	29.4±15.6	0.62±0.45
West Country	*c.* 1790–1840	2	Base	68.4±11.1	1.8±0.6	25.6±11.3	1.9±0.4
		2	Side	71.2±20.5	0.9±0.5	22.5±19.0	2.7±0.2
		2	Handle	89.6±10.7	0.9±0.4	26.5±17.6	2.2±2.8

shown that pewter produced in England from about 1600 to 1850 was generally of exceptionally fine quality, with tin content ranging between 90 and 95%. It was somewhat surprising, therefore, to find English pewter measures to be of much poorer quality. Each group of British measures does exhibit compositional consistency, however. For example, lidded baluster measures average around 70% tin while the unlidded or bulbous form contains about 82% tin.

The baluster is the earliest form of British measure and examples date from the sixteenth century. Baluster measures can be approximately dated by the stylistic variations of their thumbpieces. The wedge and wedge and ball are the earliest types known, datable to about 1625. By 1650 they were joined by the hammerhead type, and these three continued in use until about 1700 when they were superceded by the bud type. The bud thumbpiece, introduced about 1670, remained popular through the eighteenth century, gradually being replaced by the double volute which first appeared about 1740. By 1800, the double volute type had eclipsed the bud and continued to be used well into the nineteenth century (see plate 1).

The seventeen baluster measures analyzed date from the late seventeenth century through the entire eighteenth century and are representative of only the hammerhead, bud and double volute thumbpieces. During at least part of that period, the London Company and other English pewterers' guilds had certain requirements for the composition of the metal used in baluster measures. According to Michaelis (1953), 'lay' or ley metal, an alloy inferior to that used in other holloware, was permitted in the seventeenth century for use in measures, but by 1698 members of the London Company were charged 'to make wine measures of fine mettle and such work as may recommend the use thereof.'

On this basis one would expect to find the baluster measures predating 1698, i.e. those dating from the late seventeenth century, to be of poorer quality than other holloware of the same period. Such is certainly the case, for analysis of early British flagons, tankards and mugs shows them to be consistently in the 95% tin range (Carlson 1977), whereas the earliest baluster measure analyzed, a gallon sized piece with a hammerhead thumbpiece and an unidentified touch, contains only about 68% tin (table 3).

Table 3 *Analysis of English baluster measures (sides), chronological distribution*

			Weight (%)			
Type	*No.*	*Date*	*Tin*	*Copper*	*Lead*	*Antimony*
Hammerhead	1	17th cent.	67.6	3.75	25.2	0.27
Bud	5	*c.* 1690–1750	73.3 ± 1.6	1.5 ± 0.2	23.0 ± 1.2	0.30 ± 0.43
Bud	3	*c.* 1760–80	64.3 ± 2.0	1.3 ± 0.3	30.4 ± 1.8	1.6 ± 0.9
Double volute	7	*c.* 1750–1800	68.4 ± 8.3	0.95 ± 0.43	27.5 ± 7.1	0.81 ± 0.40

A slight increase in quality seems to occur with the development of the 'bud'-shaped thumbpiece. Five bud baluster measures dating from about 1690 to 1750 average about 73% tin. This temporary improvement in the alloy may well have been a result of the 1698 order issued to the members of the London Company. But as time went on, the control of the Company and other pewterers' guilds waned, and by 1750 quality standards had also declined. The three post-1750 bud baluster measures analyzed contained only about 64% tin, confirming the downward trend in tin content observed in other British-made pewter of the same period (Carlson 1977). By this time, too, the double-volute thumbpiece had become popular; the seven baluster measures of this type analyzed show an average tin content of only about 68%. Chambers' *Cyclopedia*, published in 1781, confirms that wine pots were to be made of metal containing more lead than that used for flatware or alehouse pots.

Another change in the composition of pewter was also occurring during the eighteenth century. The deliberate addition of antimony to the alloy as a hardening ingredient became more and more prevalent as the century went on, and soon became the basis for a new industry—the manufacture of objects from britannia metal. The hardness and durability of britannia metal lent itself to the new manufacturing techniques brought about by the Industrial Revolution. Britannia metal could be rolled into thin sheets, spun over a chuck on a lathe, or stamped into the desired shape. Thus bodies and bases of measures and other britannia vessels could be made of sheet metal instead of being cast in molds. However, appendages such as finials, handles and spouts continued to be cast. An examination of table 4 shows that the earliest baluster measures contained very small amounts of antimony (about 0.3%) while the amount of this metal in later bud and double volute measures increased to an average of about 1%.

Lidless pear-shaped tavern measures were a later style development, appearing around 1790 (plate 2a). Eleven measures of this type, dating from 1790 to about 1900 have been analyzed; their average chemical composition, about 83% tin, 1% copper, 13% lead and 2% antimony, seems to be significantly different from baluster measures. However, the large value for the standard deviation indicates a wide compositional variation within the group (table 3).

Three bulbous measures made by Yates or Yates & Birch of Birmingham are of high quality pewter, containing more than 95% tin in all parts. A fourth measure, with a worn oval touchmark, 'DIALS', inside the bottom dates from about the same period as the Yates measure (*c.* 1790–1830) and contains about 9[illegible]% tin. Two measures made in Bristol, one by Edgar & Son (*c.* 1840) and one by W. Rich (*c.* 1840) are markedly poorer in quality averaging about 60% tin, although the handle of the Edgar & Son measure contains nearly 98% tin. The large difference between handle and body compositions leads to speculation that the handle may in fact be a later replacement part. Two of the three very late measures analyzed, a half-pint measure (*c.* 1880–1900) and a pint measure by Brown & Englefield (*c.* 1885–1935) contain more than 80% tin, while a third late measure, gill-size with a brass rim (*c.* 1880–1900) contains only about 65% tin. Such variation is not really unexpected, for as we noted before, by the end of the eighteenth century, pewterers' guilds no longer exerted much control over the quality of wares. In addition, many Bristol pewterers concentrated on making goods intended for export to America, and as early as the 1720s, Bristol wares had a reputation for poor quality (Englefield 19[illegible]).

With regard to antimony content, note that pear-shaped tavern measures contain on the average about 2% antimony, more than found in the baluster, not surprising since they were a later style development. Curiously, the handles of bulbous measures contain considerably less antimony than other parts. In fact, six of the eleven handles contain no antimony at all while others parts of the same measures contain up to 4% antimony. Apparently, pewterers found no particular advantage to be gained from the use of antimony in parts that were cast rather than spun.

Only three Jersey measures (plate 2b) have been analyzed, but they illustrate the types of measures made on this Channel Island during three different time periods. The earliest, with a twin acorn thumbpiece and the touch of John de St Croix inside the lid, dates from about 1745 and is of relatively good quality, about [illegible]% tin. The second, a lidless measure, dating from about 1780 to 1790, is slightly poorer in quality with about 74% tin. Last, a lidless measure with a crowned 'GR' to the right of the handle, was probably made in the early nineteenth century and is of significantly poorer quality than either of the others since it contains nearly 50% lead. So again, a decline in quality with time is suggested, although the analysis of many more Jersey measures is necessary to confirm the trend.

Two West Country measures (plate 2c) used for measuring distilled spirits rather than wine, and made in Bristol (*c.* 1830–40), were analyzed. One with the mark of M. Fothergill & Sons is surprisingly high in tin content, about 86%, considering the reputation of Bristol pewter. The side of the other West Country measure, by P. Edgar & Son, contains about 57% tin, a composition more nearly that expected of a piece of late Bristol pewter; its handle, however, contains more than 97% tin. We cannot be sure whether or not this is another example of a later replacement part, but the chemical composition of this handle certainly differs dramatically from most parts of other measures tested.

SCOTTISH MEASURES

More than forty Scottish measures of various types have been analyzed. Their chemical compositions are remarkably consistent from type to type and over a period of about 150 years, although they are of significantly lower quality than their English counterparts. The analysis results for the three major types—pot-bellied, tappit-hen and baluster—are summarized in table 4.

Table 4 *X-ray fluorescence analysis of Scottish pewter measures*

				Weight (%)			
Type	*Period*	*No.*	*Part*	*Tin*	*Copper*	*Lead*	*Antimony*
Pot-bellied	*c.* 1700	9	Base	60.9 ± 2.7	1.1 ± 0.1	34.8 ± 2.0	0.51 ± 0.28
		9	Side	60.2 ± 2.5	1.0 ± 0.2	36.2 ± 2.0	0.35 ± 0.19
		8	Handle	61.3 ± 3.1	0.91 ± 0.09	35.3 ± 2.8	0.51 ± 0.29
		5	Lid	62.0 ± 3.3	0.87 ± 0.21	35.0 ± 3.0	0.36 ± 0.26
Tappit-hen	*c.* 1700–1850	12	Base	60.7 ± 4.1	1.1 ± 0.6	35.1 ± 3.1	0.66 ± 0.41
		12	Side	58.1 ± 2.3	0.87 ± 0.14	37.9 ± 2.0	0.79 ± 0.35
		12	Handle	60.6 ± 3.5	0.80 ± 0.13	35.7 ± 3.0	0.71 ± 0.53
		8	Lid	59.5 ± 1.6	0.87 ± 0.10	36.9 ± 1.2	0.51 ± 0.26
		4	Rim	60.3 ± 2.0	0.80 ± 0.09	36.3 ± 1.8	0.90 ± 0.36
Baluster	*c.* 1800	9	Side	57.9 ± 1.3	0.65 ± 0.22	38.1 ± 1.3	0.66 ± 0.37
		9	Handle	59.6 ± 1.5	0.65 ± 0.24	37.7 ± 1.4	0.56 ± 0.37
		9	Lid	58.8 ± 1.0	0.63 ± 0.19	38.1 ± 0.9	0.55 ± 0.23

The earliest variety of Scottish measure, the 'pot-bellied' or bulbous (plate 3c), dates from about 1690 to 1740. The style, probably of Continental origin, is peculiar to Scotland. The nine bulbous or 'pot-bellied' measures analyzed were quite uniform in composition, averaging about 61% tin and 36% lead with about 1% copper and 0.5% antimony. Tin was more scarce and expensive in Scotland than in England, so that Scottish pewterers had to make the most of whatever was at hand. It is interesting to note that this 61% tin–36% lead ratio is very near the composition of the tin–lead eutectic. The lowest melting point or eutectic of a binary tin-lead alloy is achieved when the tin and lead are present at the ratio of 62 parts tin to 38 parts lead. The production of objects made of such an alloy would require considerably less fuel since the alloy would be molten at 185°C as opposed to a temperature of about 220°C for a 95% tin–5% lead mixture.

Note that the average composition of the twelve tappit-hen measures (plate 3b) analysed is nearly identical to that of the earlier pot-bellied type. Two tappit-hen style measures are exceptions, however. One, dating from the early nineteenth century and marked WI is an unusual pony-sized measure which averages about 80% tin. Because of its unusual size, it may have been intended for some special purpose and hence made of a better quality alloy. The other, a crested tappit-hen, is unmarked and also dates from the early nineteenth century. It contains only about 50% tin.

Baluster measures (plate 3a) were common to both England and Scotland. But the nine Scottish baluster measures tested were again of the very uniform but low quality found in other Scottish measures. However, two baluster measures, both attributed to W. Scott, an Edinburgh pewterer, contain about 90% tin. A quart-sized measure (plate 4) with a spout and engraved 'MORE MAJORUM' (translation: in accordance with the customs of ancestors) and a measure with an unusual triple-domed lid (plate 5), may have been intended to serve as ecclesiastical vessels or as presentation pieces. They more nearly resemble ecclesiastical pewter in composition than another baluster measure attributed to W. Scott, or the bulk of Scottish baluster measures analyzed.

Scottish pewterers, even from the very earliest days, seemed to have been aware of and were able to control the quality of the alloy used in measures so as to achieve maximum utility at minimal cost.

SUMMARY

For the first time, a quantity of English and Scottish pewter measures has been chemically analyzed. The tin content of English measures is significantly less than that found in other English pewter wares. The quality of English measures, as determined by the tin content, declines over the period from 1700 to 1900, while the use of antimony in English measures increases over the same period. Scottish measures are of even poorer quality than their English counterparts, but do not change significantly in composition over the time period represented by the objects tested. Chemical composition also does not vary significantly from one type of Scottish measure to another.

ACKNOWLEDGEMENTS

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